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Chini et al.

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(45) **Date of Patent: Oct. 6, 2015**

(54) **FAST DETECTION/MITIGATION AND RECOVERY FOR SEVERE EMI CONDITIONS IN AUTOMOTIVE AREA NETWORKS**

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(51) **Int. Cl.**

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H04B 1/10	(2006.01)
H04J 11/00	(2006.01)
H04B 17/345	(2015.01)
H04W 4/00	(2009.01)
H04W 4/04	(2009.01)
H04L 25/03	(2006.01)

(52) **U.S. Cl.**

CPC .. ***H04L 1/08*** (2013.01); ***H04B 1/10*** (2013.01); ***H04B 17/345*** (2015.01); ***H04J 11/0023*** (2013.01); ***H04W 4/008*** (2013.01); ***H04W 4/046*** (2013.01); *H04L 25/03057* (2013.01)

(58) **Field of Classification Search**

CPC H04L 1/08; H04L 67/12; H04L 25/03057; H04L 1/0003; H04L 1/0025; H04L 12/40032; H04L 12/4013; H04L 12/40136; H04L 12/40156; H04L 12/40163; H04L 12/403; H04L 12/4035; H04L 12/407; H04L 12/41; H04B 17/345; H04B 1/10; H04J 11/023; H04W 4/008; H04W 4/046

See application file for complete search history.

(56) **References Cited**

U.S. PATENT DOCUMENTS

2007/0104285 A1* 5/2007 Chan et al. 375/267
2011/0201277 A1* 8/2011 Eguchi 455/63.3

(Continued)

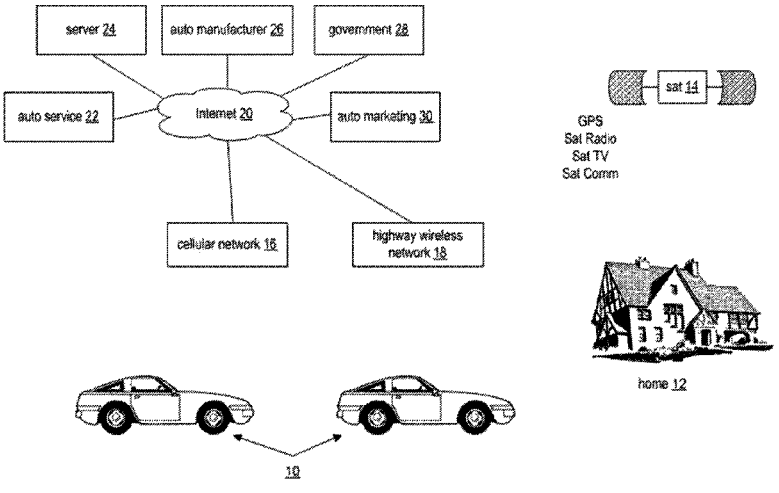
Primary Examiner — Hirdepal Singh

(74) *Attorney, Agent, or Firm* — Garlick & Markison; Bruce E. Garlick

(57) **ABSTRACT**

A vehicle communication network device includes a transceiver configured to communicatively couple with a remote transceiver of another vehicle communication network device via a wired media and processing circuitry coupled to the transceiver. The device detects interference on the wired media that exceeds an interference threshold level. Upon the detection, the device enters a quiet mode during which no data is transmitted on the wired media. After exiting the quiet mode, the device enters an idle mode during which known data is transmitted on the wired media and during which the device receives known data from the remote transceiver. The device retrains its transceiver based upon the known data and after retraining the transceiver, exchanges data with the remote transceiver. The device may also buffer data for transmission, upon the detection, determine buffered data that was likely corrupted by the interference, and after retraining, retransmit the determined buffered data.

20 Claims, 10 Drawing Sheets



(56) **References Cited**

U.S. PATENT DOCUMENTS

2013/0170439	A1*	7/2013	Anderson et al.	370/329
2013/0243052	A1*	9/2013	Barnickel et al.	375/219
2013/0264881	A1*	10/2013	Roeper et al.	307/77
2014/0024323	A1*	1/2014	Clevorn et al.	455/83
2014/0112400	A1*	4/2014	Reuven	375/258
2014/0153630	A1*	6/2014	Strobel et al.	375/229
2014/0187276	A1*	7/2014	Cyzs et al.	455/501
2014/0241282	A1*	8/2014	Mueller et al.	370/329

* cited by examiner

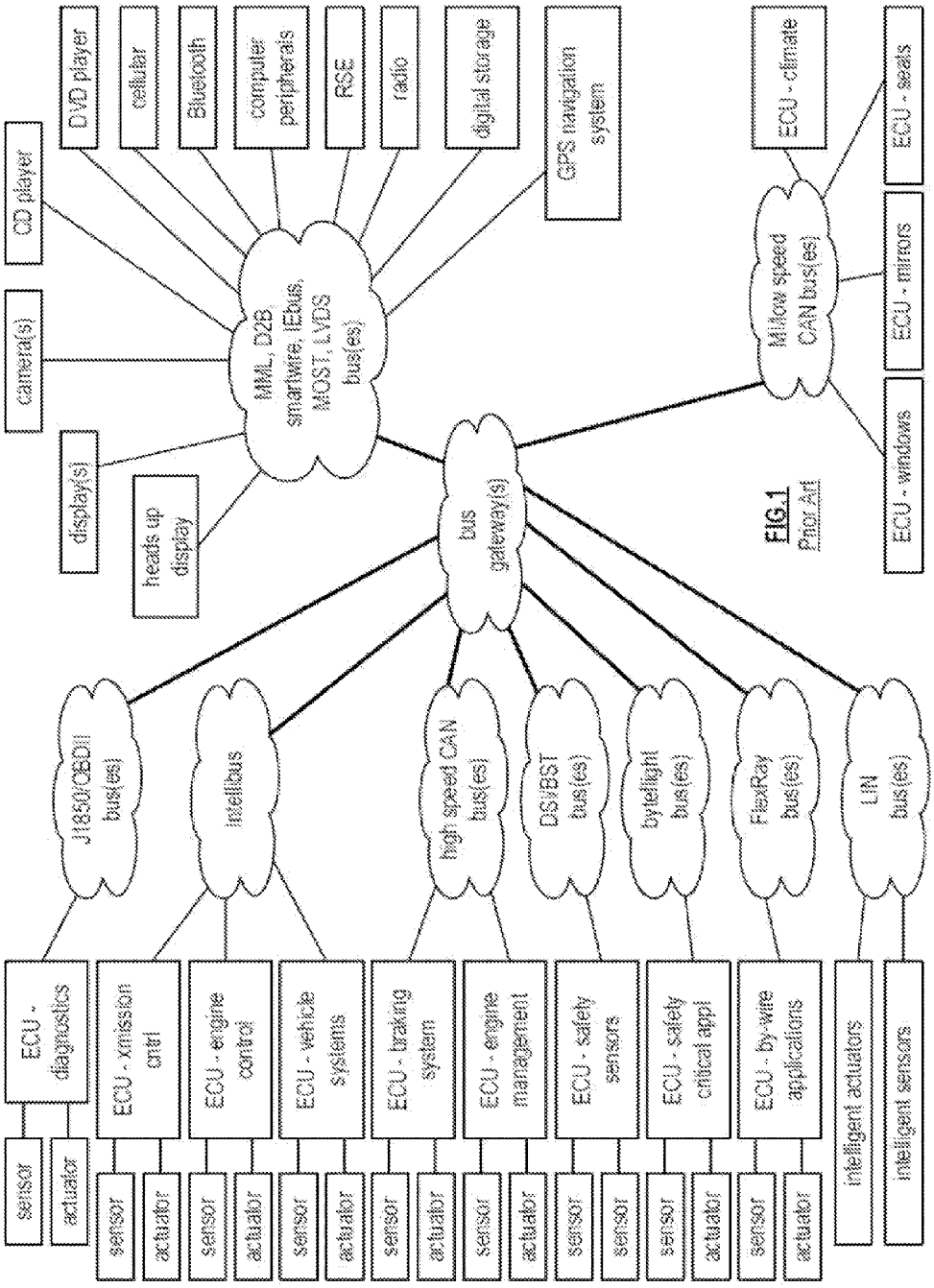


FIG.1
Prior Art

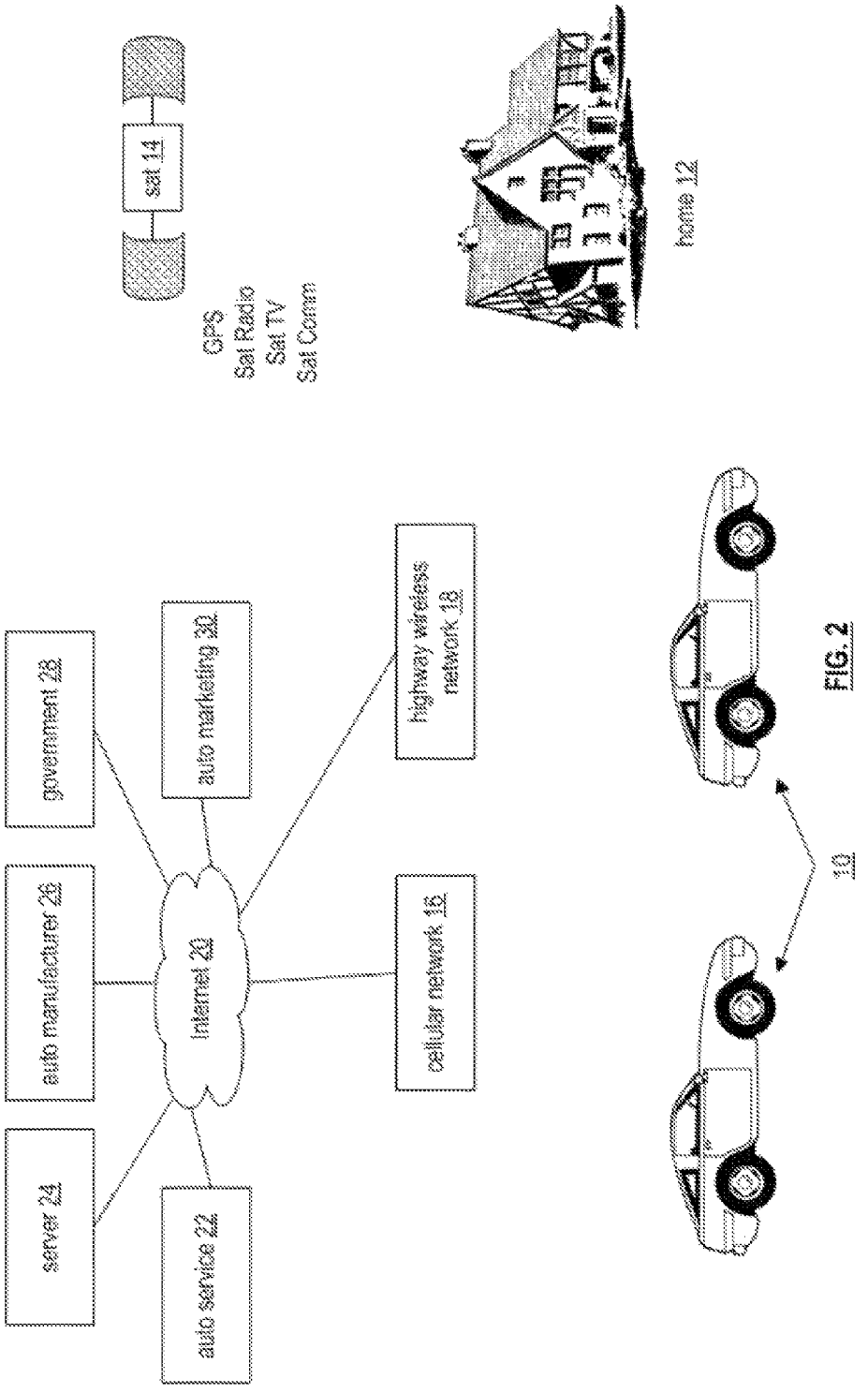

sat 14
GPS
Sat Radio
Sat TV
Sat Comm
home 12
highway wireless network 18
auto marketing 30
government 28
auto manufacturer 26
server 24
auto service 22
Internet 20
cellular network 16
10

FIG. 2

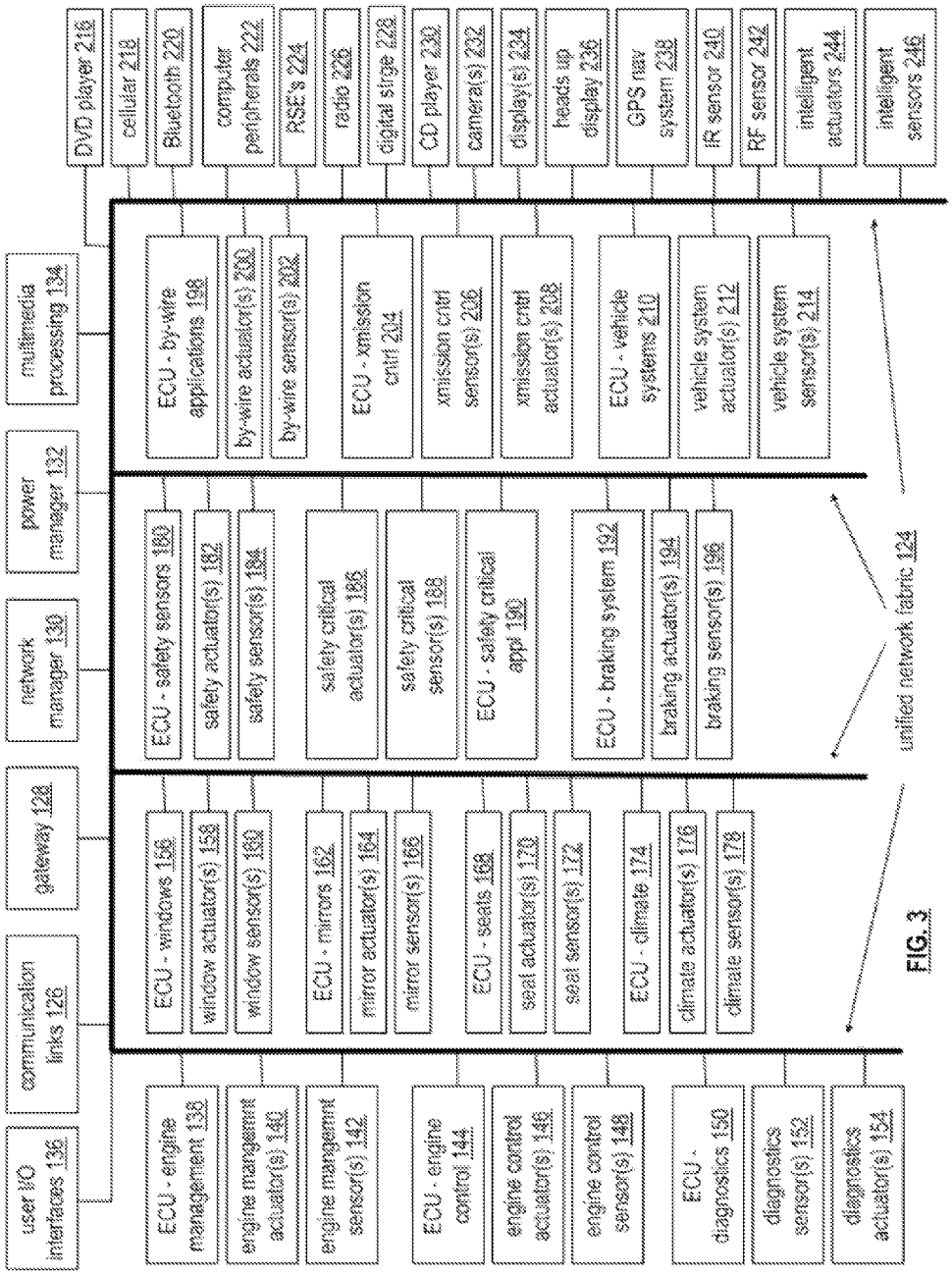

user I/O interfaces 136
communication links 126
gateway 128
network manager 130
power manager 132
multimedia processing 134
ECU - engine management 138
engine management actuator(s) 140
engine management sensor(s) 142
ECU - engine control 144
engine control actuator(s) 146
engine control sensor(s) 148
ECU - diagnostics 150
diagnostics sensor(s) 152
diagnostics actuator(s) 154
ECU - windows 156
window actuator(s) 158
window sensor(s) 160
ECU - mirrors 162
mirror actuator(s) 164
mirror sensor(s) 166
ECU - seats 168
seat actuator(s) 170
seat sensor(s) 172
ECU - climate 174
climate actuator(s) 176
climate sensor(s) 178
ECU - safety sensors 180
safety actuator(s) 182
safety sensor(s) 184
safety critical actuator(s) 186
safety critical sensor(s) 188
ECU - safety critical appl 190
ECU - braking system 192
braking actuator(s) 194
braking sensor(s) 196
ECU - by-wire applications 198
by-wire actuator(s) 200
by-wire sensor(s) 202
ECU - xmission cntrl 204
xmission cntrl sensor(s) 206
xmission cntrl actuator(s) 208
ECU - vehicle systems 210
vehicle system actuator(s) 212
vehicle system sensor(s) 214
unified network fabric 124
DVD player 216
cellular 218
Bluetooth 220
computer peripherals 222
RSE's 224
radio 226
digital stirge 228
CD player 230
camera(s) 232
display(s) 234
heads up display 236
GPS nav system 238
IR sensor 240
RF sensor 242
intelligent actuators 244
intelligent sensors 246

FIG. 3

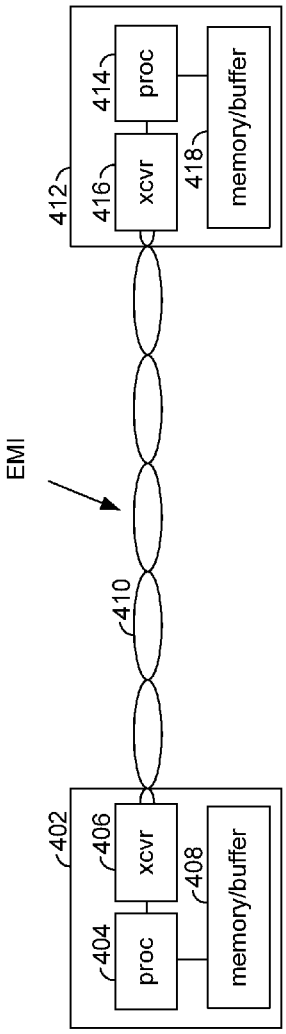

EMI
410
402
406
xcvr
408
memory/buffer
404
proc
412
416
xcvr
418
memory/buffer
414
proc

FIG. 4A

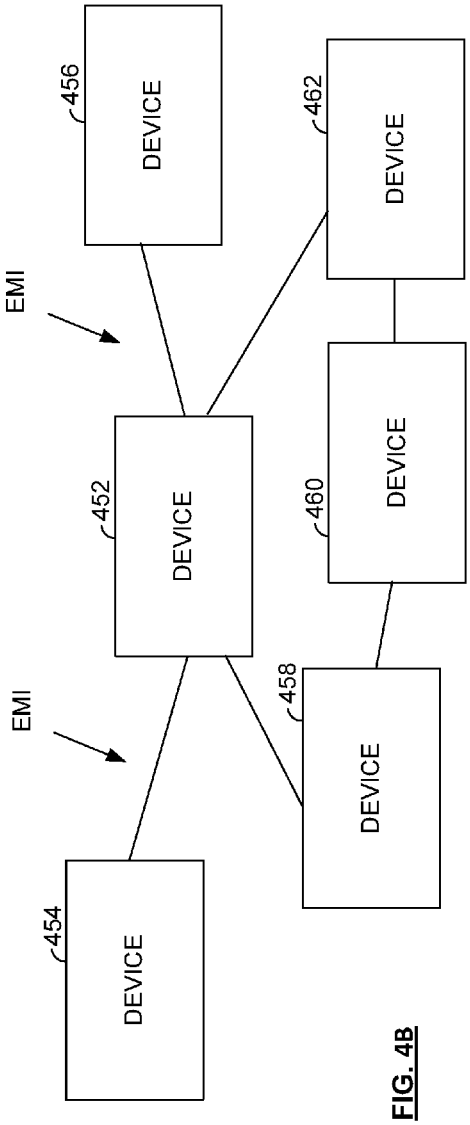

EMI
EMI
EMI
452
DEVICE
454
DEVICE
456
DEVICE
458
DEVICE
460
DEVICE
462
DEVICE

FIG. 4B

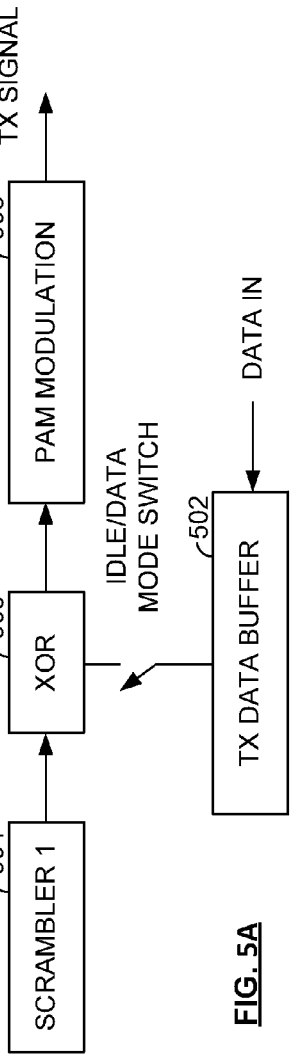

TX SIGNAL
508
PAM MODULATION
506
XOR
IDLE/DATA
MODE SWITCH
502
TX DATA BUFFER
DATA IN
504
SCRAMBLER 1

FIG. 5A

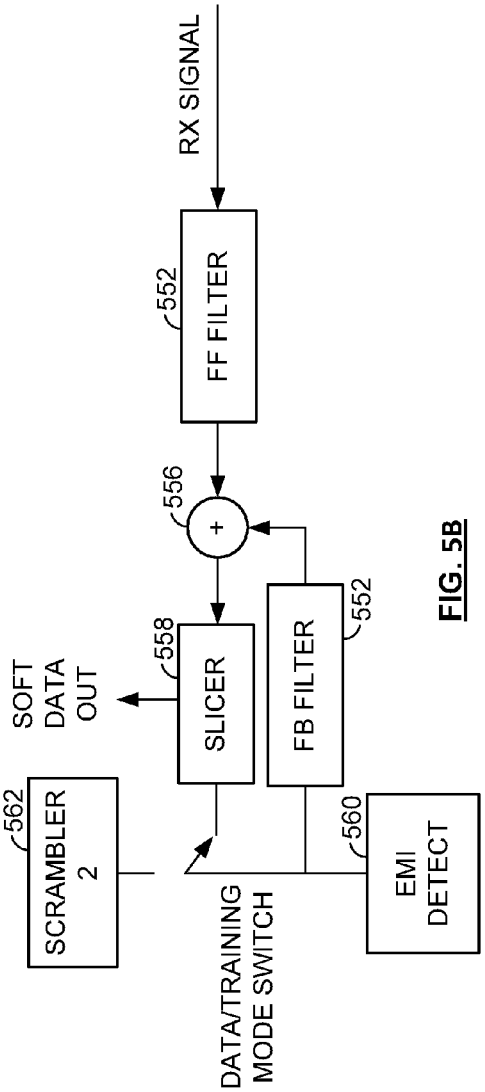

RX SIGNAL
552
FF FILTER
556
+
558
SLICER
552
FB FILTER
SOFT
DATA
OUT
562
SCRAMBLER
2
560
EMI
DETECT
DATA/TRAINING
MODE SWITCH

FIG. 5B

FIG. 6A

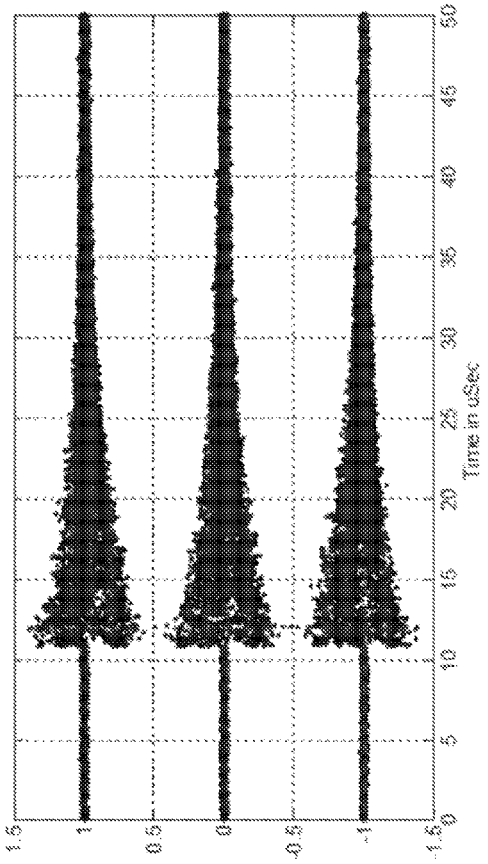
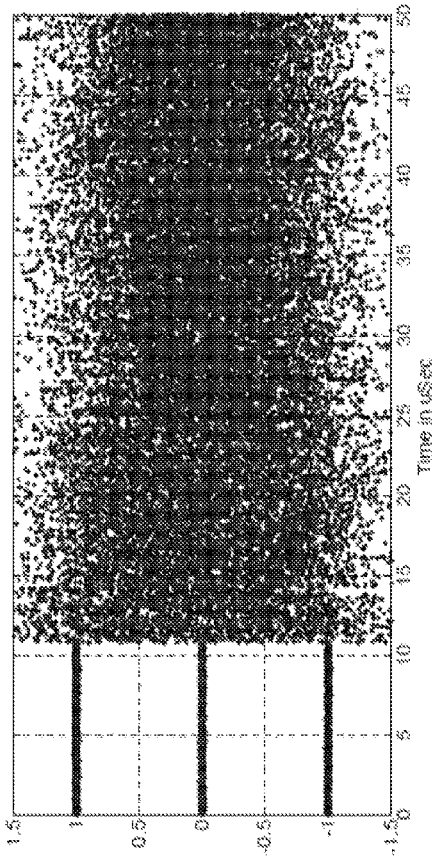

1.5
1
0.5
0
-0.5
-1
-1.5
0
5
10
15
20
25
30
35
40
45
50
Time in uSec

FIG. 6B


1.5
1
0.5
0
-0.5
-1
-1.5
0
5
10
15
20
25
30
35
40
45
50
Time in uSec

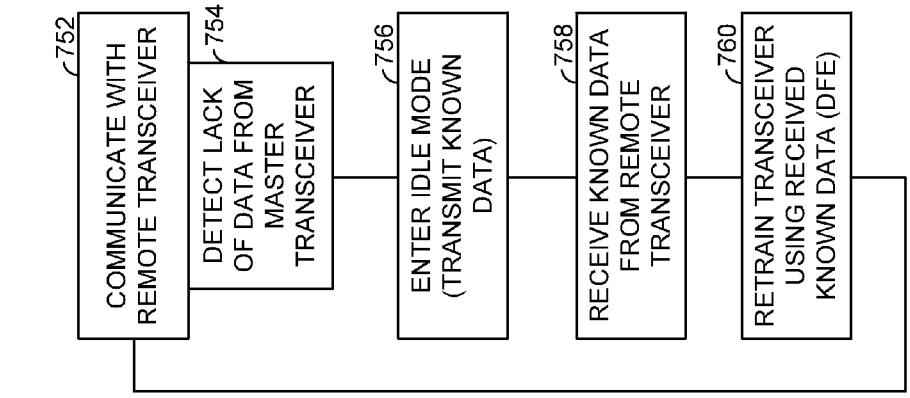

752
COMMUNICATE WITH REMOTE TRANSCEIVER
754
DETECT LACK OF DATA FROM MASTER TRANSCEIVER
756
ENTER IDLE MODE (TRANSMIT KNOWN DATA)
758
RECEIVE KNOWN DATA FROM REMOTE TRANSCEIVER
760
RETRAIN TRANSCEIVER USING RECEIVED KNOWN DATA (DFE)

FIG. 7B

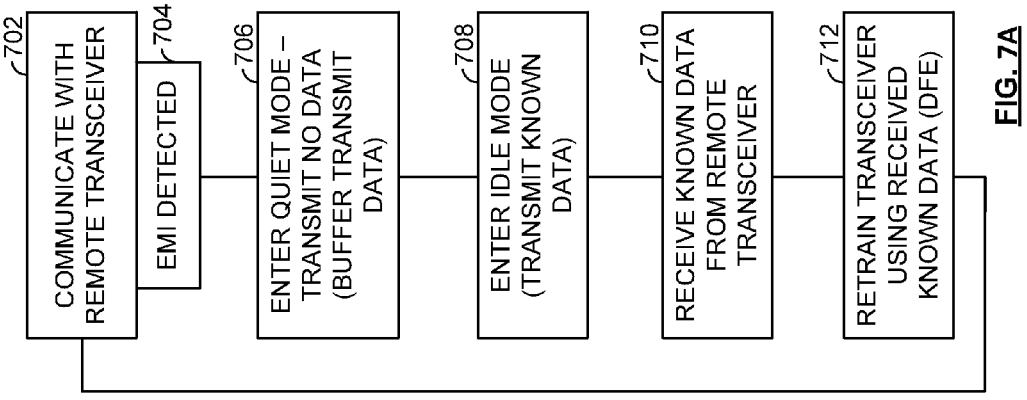

702
COMMUNICATE WITH REMOTE TRANSCEIVER
704
EMI DETECTED
706
ENTER QUIET MODE – TRANSMIT NO DATA (BUFFER TRANSMIT DATA)
708
ENTER IDLE MODE (TRANSMIT KNOWN DATA)
710
RECEIVE KNOWN DATA FROM REMOTE TRANSCEIVER
712
RETRAIN TRANSCEIVER USING RECEIVED KNOWN DATA (DFE)

FIG. 7A

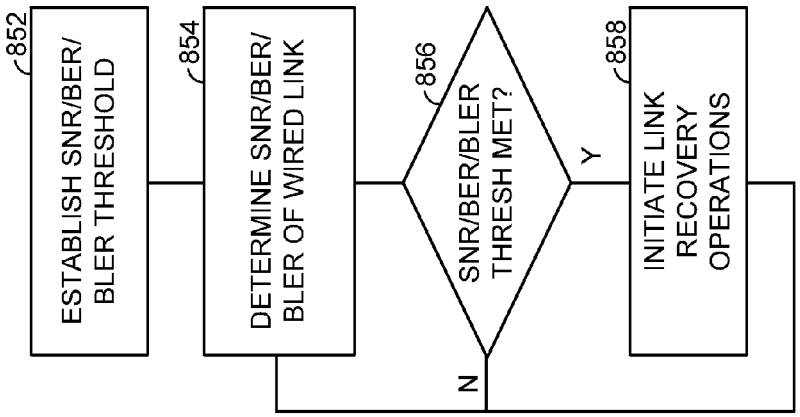

852
ESTABLISH SNR/BER/ BLER THRESHOLD
854
DETERMINE SNR/BER/ BLER OF WIRED LINK
856
SNR/BER/BLER THRESH MET?
Y
N
858
INITIATE LINK RECOVERY OPERATIONS

FIG. 8B

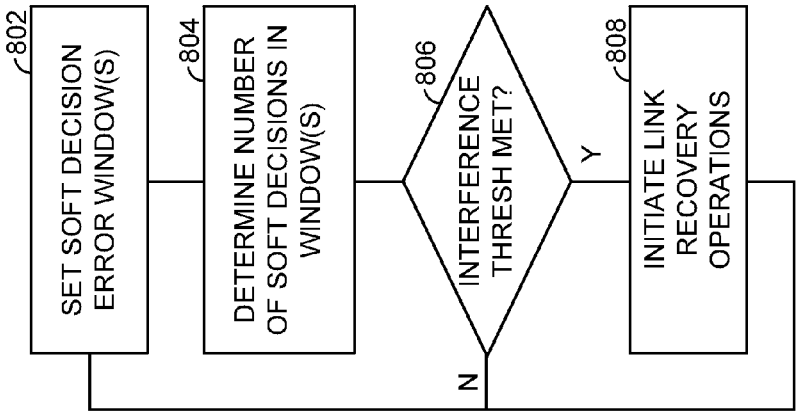

802
SET SOFT DECISION ERROR WINDOW(S)
804
DETERMINE NUMBER OF SOFT DECISIONS IN WINDOW(S)
806
INTERFERENCE THRESH MET?
Y
N
808
INITIATE LINK RECOVERY OPERATIONS

FIG. 8A

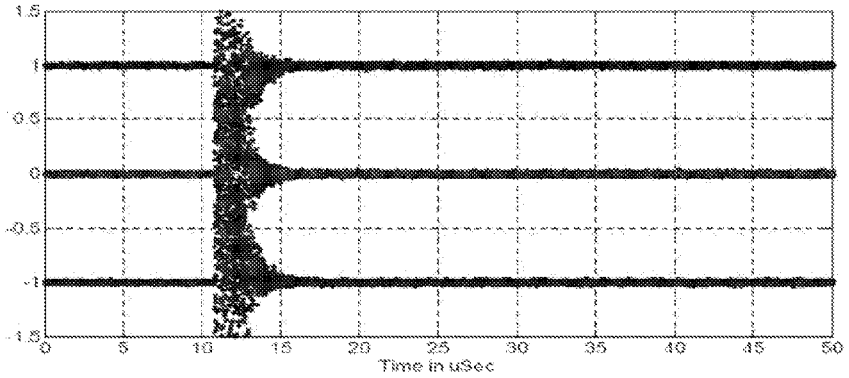


FIG. 9A

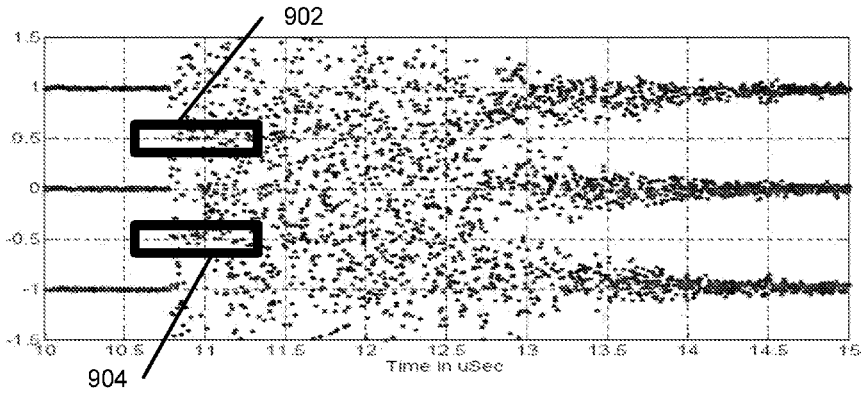


FIG. 9B

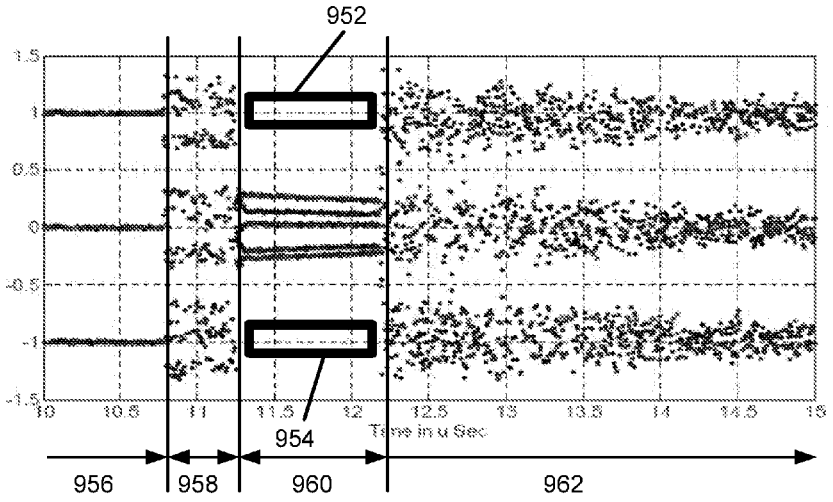


FIG. 9C

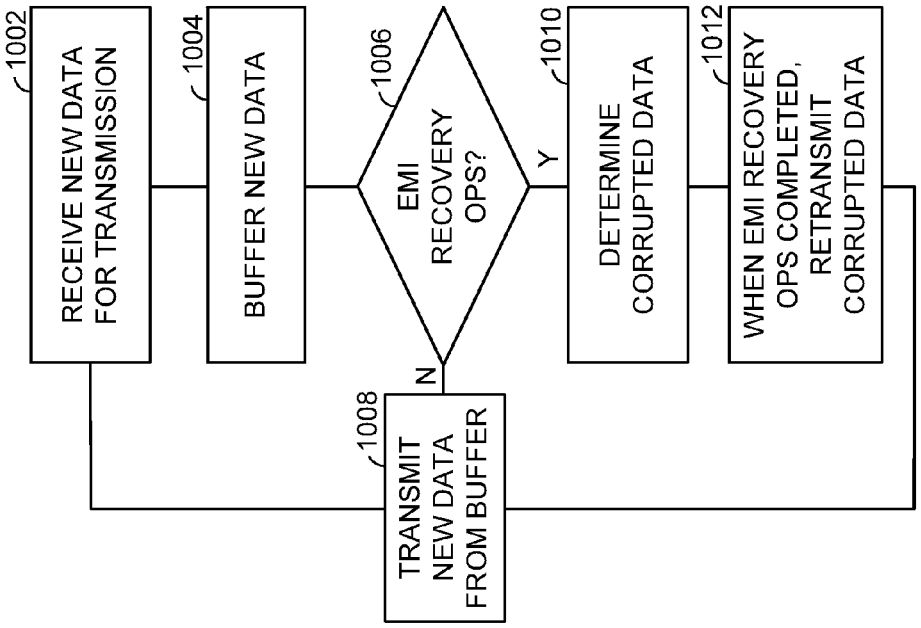

1002
RECEIVE NEW DATA FOR TRANSMISSION
1004
BUFFER NEW DATA
1006
EMI RECOVERY OPS?
Y
1010
DETERMINE CORRUPTED DATA
1012
WHEN EMI RECOVERY OPS COMPLETED, RETRANSMIT CORRUPTED DATA
N
1008
TRANSMIT NEW DATA FROM BUFFER

FIG. 10

FAST DETECTION/MITIGATION AND RECOVERY FOR SEVERE EMI CONDITIONS IN AUTOMOTIVE AREA NETWORKS

CROSS REFERENCE TO PRIORITY APPLICATIONS/INCORPORATION BY REFERENCE

The present U.S. Utility Patent Application claims priority pursuant to 35 U.S.C. §119(e) to U.S. Provisional Application No. 61/876,558, entitled "Fast Detection/Mitigation and Recovery for Severe EMI Conditions in Automotive Area Networks," filed Sep. 11, 2013, which is hereby incorporated herein by reference in its entirety and made part of the present U.S. Utility Patent Application for all purposes.

STATEMENT REGARDING FEDERALLY SPONSORED RESEARCH OR DEVELOPMENT

Not Applicable

INCORPORATION-BY-REFERENCE OF MATERIAL SUBMITTED ON A COMPACT DISC

Not Applicable

BACKGROUND

1. Technical Field

This disclosure relates generally to communications and more particularly to data and multimedia communications within a vehicle.

2. Description of Related Art

As is known, a vehicle (e.g., automobile, truck, bus, an agricultural vehicle, ship, and/or aircraft) includes a vehicle communication network. The complexity of the vehicle communication network varies depending on the number and complexity of electronic devices within the vehicle. For example, advanced vehicles include electronic modules for engine control, transmission control, antilock braking, body control, emissions control, etc. To support the various electronic devices within the vehicle, the automotive industry has generated numerous communication protocols.

FIG. **1** is a schematic block diagram of a prior art vehicular communication network that illustrates the various bus protocols and the electronic devices that utilize such protocols. The bus protocols include: (1) J1850 and/or OBDII, which are typically used for vehicle diagnostic electronic components; (2) Intellibus, which is typically used for electronic engine control, transmission control or other vehicle systems such as climate control, and it may also be used for drive-by-wire electronic control units (ECU); (3) high-speed controller area network (CAN), which is typically used for braking systems and engine management systems; (4) distributed system interface (DSI) and/or Bosch-Siemens-Temic (BST), which is typically used for safety related electronic devices; (5) byteflight, which is typically used for safety critical electronic device applications; (6) local interconnect network (LIN), which is typically used for intelligent actuators and/or intelligent sensors; (7) low-speed controller area network (CAN) and/or Motorola® interconnect (MI), which are typically used for low-speed electronic devices such as Windows, minors, seats and/or climate control; (8) mobile media link (MML), domestic digital data (D2B), smartwireX, inter-equipment bus (IEBus), and/or media oriented systems transport (MOST), which are typically used to support multimedia electronic devices within a vehicle such as a audio head unit and amplifiers, CD player, a DVD player, a cellular connection, a Bluetooth connection, peripheral computer connections, rear seat entertainment (RSE) units, a radio, digital storage, and/or a GPS navigation system; (9) Low-Voltage Differential Signaling (LVDS), which are typically used to support heads up display, instrument panel displays, other digital displays, driver assist digital video cameras, and (10) FlexRay, which may be used for safety critical features and/or by-wire applications.

Not only are the multiple communication networks within the vehicle complex, but they also typically require separate wiring for each group of devices that share common protocol(s). A typical vehicle includes 400 to 600 pounds of wiring, which makes wiring the second heaviest component in a vehicle; the engine is the heaviest. Integrating the multiple vehicle communication networks into fewer networks is desirable not only for reduction in complexity but also to reduce wiring needs. Unfortunately, reduction in wiring and using lower cost wiring makes the vehicular communication network(s) more susceptible to Electro Magnetic Interference (EMI), which adversely affects intra-vehicle communications and vehicle reliability.

BRIEF DESCRIPTION OF THE SEVERAL VIEWS OF THE DRAWING(S)

FIG. **1** is a block diagram illustrating a prior art intra-vehicular communication network;

FIG. **2** is a system diagram illustrating a communication system in accordance with the present disclosure;

FIG. **3** is a block diagram illustrating an embodiment of a vehicular communication network in accordance with the present disclosure;

FIG. **4**A is a block diagram illustrating two devices coupled and operating according to an embodiment of the present disclosure;

FIG. **4**B is a block diagram illustrating a plurality of devices coupled and operating according to an embodiment of the present disclosure;

FIG. **5**A is a block diagram illustrating transmit components and operation thereof of a device in accordance with the present disclosure;

FIG. **5**B is a block diagram illustrating receive components and operation thereof of a device in accordance with the present disclosure;

FIG. **6**A is a graph illustrating operation of a communication link in accordance with the present disclosure compensating for minor to moderate Electro Magnetic Interference (EMI);

FIG. **6**B is a graph illustrating operation of a communication link that is unable to compensate for severe EMI;

FIG. **7**A is a flow chart illustrating operation of a device operating as a master in accordance with the present disclosure;

FIG. **7**B is a flow chart illustrating operation of a device operating as a slave in accordance with the present disclosure;

FIG. **8**A is a flow chart illustrating EMI detection operations in accordance with the present disclosure;

FIG. **8**B is a flow chart illustrating differing EMI detection operations according to an embodiment in accordance with the present disclosure;

FIG. **9**A is a graph illustrating EMI detection and recovery operations of a master device in accordance with the present disclosure;

FIG. **9**B is a graph illustrating EMI detection operations of a master device in accordance with the present disclosure;

FIG. **9C** is a graph illustrating EMI detection and recovery operations of a slave device in accordance with the present disclosure; and

FIG. **10** is a flow chart illustrating data buffering and retransmission operations in accordance with the present disclosure.

DETAILED DESCRIPTION OF THE DISCLOSURE

FIG. **2** is a system diagram illustrating a communication system in accordance with the present disclosure. The communication system includes vehicles **10**, a home network **12**, a satellite transceiver **14**, a cellular network **16**, a highway wireless network **18**, the Internet **20**, an automobile service provider **22**, a server **24**, an automobile manufacturer **26**, government **28**, and/or automobile marketing **30**. In this system, each vehicle **10** includes a packet/frame-based communication network that enables it to communicate with other vehicles, with its home network **12**, with the satellite transceiver **14** (GPS, satellite radio, satellite TV, satellite communication, etc.), with the cellular network **16**, and/or with the highway wireless network **18**. Note that the highway wireless network **18** may include a plurality of wireless transceivers located proximal to highways, roads, rest areas, etc.

In an example of operation, a vehicle **10** may communicate with an automobile service provider **22** (e.g., engine tune-up, brake system, a transmission system, etc.) via the cellular network **16**, the highway wireless network **18**, and/or its home network **12**. Such a communication includes the vehicle **10** transmitting data regarding its operational status (e.g., number of hours since last engine tune-up, wear & tear on the break system, brake fluid level, oil level, transmission fluid level, etc.). The automobile service provider **22** interprets the operational status data to determine if the vehicle **10** is in need of service and/or if a component failure is likely to occur in the near future. Based on this interpretation, the automobile service provider **22** sends data to the vehicle indicating whether service is needed and may further include data to schedule an appointment for such service.

In another example of operation, a vehicle **10** collects data regarding its performance (e.g., fuel efficiency, component wear & tear, real-time engine control, real-time braking system control, real-time transmission control, etc.), which it transmits to the auto manufacturer **26**. The auto manufacturer **26** utilizes the data for a variety of purposes, such as improving future designs, determining need for recalls, etc.

In yet another example of operation, a vehicle **10** may communicate with a server to upload data and/or download data. As a more specific example, the server may provide streaming video of television shows, movies, etc. For a subscription fee, the vehicle **10** downloads the streaming video for display on rear seat entertainment systems and/or other displays within the vehicle. As another specific example, the vehicle **10** may upload data (e.g., video taken by cameras of the car, user data contained on a laptop computer, video game inputs and/or controls, etc.) to the server.

In a further example of operation, the vehicle **10** may communicate with a government agency **28** (e.g., driver motor vehicle) to update registration information, insurance information, etc. As another example, the vehicle **10** may communicate specific performance information (e.g., general vehicle operation, emissions test, etc.) with the government agency **28** for compliance with different government programs (e.g., emissions control, safety check, etc.).

In a still further example of operation, the vehicle **10** may receive marketing information from an auto-marketing provider **30**. For instance, the vehicle **10** may receive commercial information based on the vehicle's location, driver's interests, recent communications to and/or from the vehicle, etc.

According to the present disclosure one or more devices of vehicle **10** include structure and supported operations to resist and recover from severe Electro Magnetic Interference (EMI) that affects communications serviced by such devices. EMI may be caused by neighboring vehicles, caused by internal or external RF communications, radar guns, electronic devices within the vehicle **10**, and by various other EMI sources. The structure and operation of the present disclosure consistent therewith will be described in detail with reference to FIGS. **4A-10**.

FIG. **3** is a block diagram illustrating an embodiment of a vehicular communication network in accordance with the present disclosure. The vehicular communication network includes a unified network fabric **124**, one or more communication links **126**, and a plurality of devices including a gateway **128**, a network manager **130**, a power manager **132**, one of more multimedia processing modules **134**, a plurality of user input and/or output interfaces **136** (e.g., seat adjust, window control, radio control, mirror control, GPS control, cruise control, etc.), and a plurality of other devices. These other devices may include one or more of each of an engine management electronic control unit **138**, an engine management actuator **140**, an engine management sensor **142**, an engine control electronic control unit **144**, an engine control actuator **146**, an engine control sensor **148**, a diagnostic electronic control unit **150**, a diagnostic sensor **152**, a diagnostic actuator **154**, a window electronic control unit **156**, a window actuator **158**, a window sensor **160**, a minor electronic control unit **162**, a minor actuator **164**, a minor sensor **166**, a seat electronic control unit **168**, a seat actuator **170**, a seat sensor **172**, a climate electronic control unit **174**, a climate actuator **176**, a climate sensor **178**, a safety sensor electronic control unit **180**, a safety actuator **182**, a safety sensor **184**, a safety critical application electronic control unit **186**, a safety critical actuator **188**, a safety critical sensor **190**, a braking system electronic control unit **192**, a breaking actuator **194**, a breaking sensor **196**, a by-wire application electronic control unit **198**, a by-wire actuator **200**, a by-wire sensor **202**, a transmission control electronic control unit **204**, a transmission control sensor **206**, a transmission control actuator **208**, a vehicle system electronic control unit **210**, a vehicle system actuator **212**, a vehicle system Sensor **214**, a DVD player **216**, a cellular telephone interface **218**, a Bluetooth interface **220**, a computer peripheral interface **222**, a rear seat entertainment interface and/or unit **224**, a radio **226**, digital storage **228**, a CD player **230**, a camera **232**, a display **234**, a heads-up display **236**, a GPS navigation system **238**, an infrared sensor **240**, a radio frequency sensor **242**, an intelligent actuator **244**, and/or an intelligent sensor **246**.

In FIG. **3**, the devices interconnect via the unified network fabric **124**. The unified network fabric **124** may inter couple the devices in various configurations including ring configurations, star configurations, direct links, etc. In any of these configurations, one device directly connects to another device via a wired and/or a wireless connection. In some embodiments, these connections will be via Unshielded Twisted Pair (UTP) wiring and use one or more communication protocols, e.g., as described with reference to the prior art in FIG. **1** or one or more new communication protocols. In any case, when communications are serviced via UTP wiring (or other unshielded or marginally shielded wiring), they are susceptible to EMI. As will be described further with reference to FIG. **4A**, each device includes structure sufficient to withstand some level of EMI using standard filtering components,

e.g., Feed Forward Equalizers (FFEs), Decision Feedback Equalizers (DFEs), and/or various other types of filters/equalizers that are resistant to EMI. However, when EMI is severe, these conventional components cannot service communications in an acceptable manner.

Thus, according to the present disclosure, one or more devices illustrated in FIG. **3** include structure and support operations to resist and recover from moderate to severe EMI. The structure and operation of these devices will be described in detail with reference to FIGS. **4A-10**. In short, this structure and supported operations provide fast recovery of communication link service when moderate to severe EMI disrupts communications on unshielded or moderately protected wiring.

FIG. **4A** is a block diagram illustrating two devices **402** and **412** coupled and operating according to an embodiment of the present disclosure. Each of these devices **402** and **412** may be one of the devices illustrated in FIG. **3**. Device **402** includes a transceiver **406**, a processor **404**, and memory/buffer **408**. Device **412** includes a transceiver **416**, a processor **414**, and memory/buffer **418**. The transceivers **406** and **416** communicatively couple via wired link **410**. Each of the processors **404** and **414** may be one or more of a general purpose processor, a digital signal processor, digital logic and/or other circuitry capable of performing processing operations to support a functional purpose of the respective device **402** or **412**. Memory/buffer **408** or **418** may be any type of memory capable of storing data and/or software instructions that is operated upon by processors **404** or **414**, respectively. The processing circuitry **404**, transceiver **406**, and memory/buffer **408** support the required functionality of device **402**. Likewise, the processing circuitry **414**, transceiver **416**, and memory/buffer **418** support the required functionality of device **412**. The wired media may be UTP and be subject to EMI. Thus the devices **402** and **412** operate according to the concepts of the present disclosure to recover from severe EMI that will be described further herein. One of the devices **402** may provide power to the other device **412** via the wired link **410**. Further, the devices **402** and **412** may provide power to each other via the wired link **410**.

FIG. **4B** is a block diagram illustrating a plurality of devices coupled and operating according to an embodiment of the present disclosure. Each of these devices **452**, **454**, **456**, **458**, **460**, and **462** has same/similar structure as do the devices **402** and **412** of FIG. **4A**. As shown, these devices **452**, **454**, **456**, **458**, **460**, and **462** inter couple with one another via wired links and are subject to EMI. Thus, these devices **452**, **454**, **456**, **458**, **460**, and **462** also operate according to the concepts of the present disclosure to recover from sever EMI as is described further herein.

FIG. **5A** is a block diagram illustrating transmit components and operation thereof of a communication device in accordance with the present disclosure. These components include a TX data buffer **502** that receives data for transmission. The TX data buffer **502** may be serviced by the memory/buffers **408** and/or **418** of FIG. **4A**. When the transmit components are transmitting data on the wired media, the TX data buffer **502** couples transmit data to the eXclusive OR (XOR) block **506**, which combines the transmit data with the output of scrambler 1 **504**. The output of the XOR block **506** is received by Pulse-Amplitude Modulation (PAM) block **508**, which modulates the output to produce a TX signal. The TX signal is coupled to the wired media, intended for receipt by a remote device coupled via the wired media.

FIG. **5B** is a block diagram illustrating receive components and operation thereof of a device in accordance with the present disclosure. The receive components include a Feed Forward Filter **552**, summer **556**, a Feed Back Filter **552**, and data slicer **558**, which, during receive operations are considered a Decision Feedback Equalizer (DFE) and coupled in such a configuration where the output of the data slicer **558** serves as input to the Feed Back Filter **552**. The slicer **558** produces soft decisions as its output (soft data). EMI detection circuitry **560** detects when EMI present on the wired link exceeds a threshold. When such EMI is detected, the components of both FIGS. **5A** and **5B** operate to recover the serviced link as described further herein. As will be described herein, during recovery mode, scrambler 2 **562** provides known data to the Feed Back Filter **552** for training.

The transmit components of FIG. **5A** and the receive components of FIG. **5B** service high speed communications, e.g., high speed Ethernet technologies that may support communications similar to IEEE 802.3bp Reduced Twisted Pair Gigabit Ethernet or RTPGE. The components of FIGS. **5A** and **5B** may operate in one or both of master and slave modes. When in the master mode, the components of FIGS. **5A** and **5B** control the communication links serviced thereby. When in the slave mode, the components of FIGS. **5A** and **5B** are responsive to the master of the communication link.

UTP cables are of special interest in automotive applications because of cost and longevity in automotive environment. A major challenge for operating at Giga bit speed over UTP cables is immunity to Radio Interference or EMI. For automotive applications, there are many sources for radio interference including; Citizen band Radios, Ham Radios, Short wave transmitters, TV transmitters, Digital Audio Broadcasting, Mobile base stations, and radio transceivers on Emergency vehicles. Significant noise voltage may be coupled into the UTP cable operating at Giga bit speed. Typically higher rate transmission is subject to more Radio interference because balance of cables and connectors are worse at higher frequencies. UTP cables, connectors, and magnetics are designed as such to minimize the noise at the receiver. The remainder noise is expected to be tolerated or rejected by Physical layer or PHY design.

The PHY design of the devices of FIGS. **5A** and **5B** should mitigate radio interference while containing radio emission. The emission limits do not allow transmitting signals at more than certain levels. At these limited transmit levels the received radio noise may exceed the levels acceptable for data communication. Proper signal processing techniques are required to mitigate and reject radio interferences under such conditions. To allow rejecting radio interference, wide band modulation techniques are used with bandwidth significantly larger than the radio interferences. Narrow band interference can then be rejected in the equalizer used primarily to mitigate inter-symbol interference.

When the interference is at a moderate level, the DFE adapts automatically to reject (notch out) narrow band EMI. If strong EMI appears suddenly at the receiver, the DFE may become corrupted with too many errors to the point the DFE may be unable to adapt to the EMI and reject the EMI using decision feedback operations. The effects are worse when higher level modulations are used. During these operations, the EMI detection circuitry **560** initiates link recovery operations.

FIG. **6A** is a graph illustrating operation of a communication link in accordance with the present disclosure compensating for minor to moderate EMI. FIG. **6A** particularly illustrates soft decisions at the slicer **558** input where it is corrupted with moderate EMI. In this case, the DFE automatically adapts to the EMI and the narrowband EMI is rejected in the Feed-Forward filter by rejecting the narrow band noise.

FIG. 6B is a graph illustrating operation of a communication link that is unable to compensate for severe EMI. In particular, FIG. 6B shows soft decisions at the slicer **558** input where it is corrupted with EMI that is about 10 dB greater than the EMI illustrated in FIG. 6A. When strong EMI is suddenly applied, for example when an emergency vehicle suddenly turns on its transmitter, too many errors are circulated in the DFE Feed-Back filter **552** and the DFE completely loses its state and is not able to recover its state.

FIG. 7A is a flow chart illustrating operation of a device operating as a master in accordance with the present disclosure. The operations of FIG. 7A begin with the device communicating with a remote device via wired media, e.g., UTP wiring (Step **702**). The device operates as the master of the link and the remote device operates as the slave of the link. Operation continues with the device detecting that interference, e.g., EMI, on the wired media exceeds an interference threshold level (Step **704**). Detecting that the interference exceeds a threshold is described further with reference to FIGS. **8**A, **8**B, **9**A, and **9**B.

Upon the detection, the device enters a quiet mode during which no data is transmitted on the wired media (Step **706**). Referring to FIG. **5**A, in the quiet mode, the TX data buffer **502** is disconnected from XOR block **506**. Further, the output of scrambler 1 **504** may be interrupted so that the XOR block **506** produces no data for output. Alternately, the PAM modulator **508** may be disabled to enable the quiet mode.

Referring again to FIG. 7A, after exiting the quiet mode, the device enters an idle mode during which known data is transmitted on the wired media (Step **708**). In this operation, the TX data buffer **502** is still disconnected from the XOR block **506** but the scrambler 1 **504** provides a scrambling code that the XOR block **506** uses to provide known data at its output, which the PAM modulate block **508** modulates to produce the known data in a modulated transmission format. At this point in the operation, the remote slave device has begun transmitting known data, which is received by the device (**710**). The device uses the known data to retrain its DFE (Step **712**). After retraining is completed, operation returns to step **702** where data is continued to be exchanged with the remote device.

FIG. 7B is a flow chart illustrating operation of a device operating as a slave in accordance with the present disclosure. The operations of FIG. 7B begin with the remote device (slave) communicating with the device (master) via a wired media (Step **752**). Operation continues with the device detecting a lack of data being transmitted from the master device (Step **754**, corresponding to step **708** of FIG. 7A) and entering a quiet mode in which it transmits no data on the wired link. Referring to FIG. **5**A, in the quiet mode, the TX data buffer **502** is disconnected from XOR block **506**. Further, the output of scrambler 1 **504** may be interrupted so that the XOR block **506** produces no data for output. Alternately, the PAM modulator **508** may be disabled to enable the quiet mode.

Referring again to FIG. 7B, after exiting the quiet mode, the device enters an idle mode during which known data is transmitted on the wired media (Step **756**). In this operation, the TX data buffer **502** is still disconnected from the XOR block **506** but the scrambler 1 **504** provides a scrambling code that the XOR block **506** uses to provide known data at its output, which the PAM modulate block **508** modulates to produce the known data in a modulated transmission format. At this point in the operation, the remote master device has begun transmitting known data, which is received by the slave device (Step **758**). The slave device uses the known data to retrain its DFE (Step **760**). After retraining is completed, operation returns to step **752** where data is continued to be exchanged with the remote device.

FIG. 8A is a flow chart illustrating EMI detection operations in accordance with the present disclosure. With the operations of FIG. 8A, the device establishes one or more soft decision error windows (Step **802**). FIG. 9A is a graph illustrating EMI detection and recovery operations of a master device in accordance with the present disclosure. FIG. 9B is a graph illustrating EMI detection operations of a master device in accordance with the present disclosure. FIG. 9B spans across a short duration of FIG. 9A to show in detail soft decision error windows **902** and **904**, which slide in time with the receipt of soft data produced by the slicer **558** of FIG. 5B. The soft decision error windows reside about decision points at 0.5 and −0.5 at which no data is expected. Referring to both FIG. 8A and FIG. 9B, a number of soft decisions that reside within the soft decision error windows **902** and **904** is determined (Step **804**). When these determined numbers exceed a predetermined count, the interference threshold is met at Step **806** and operation proceeds to Step **808** where error recovery operations are initiated. If the interference threshold is not met at Step **806**, operation returns to Step **802** where the soft decision error window(s) are reset.

FIG. 9C is a graph illustrating EMI detection and recovery operations of a slave device in accordance with the present disclosure. The graph is divided into four distinct time periods. During time period **956**, the wired link is operational with no or only minor EMI present and DFE operation is stable enough to accommodate any noise that is present. During time period **958**, EMI is present on the link at sufficient levels to interrupt normal operation of the wired link. During period **958** the master device decides to enter link recovery operations. During time period **960**, the master device has entered the idle mode in which it does not transmit data. In this mode, all decisions are near zero, with the lack of transmitted data affected only by the EMI on the wired link.

The slave device establishes sliding idle mode detection windows **952** and **954** similarly to the manner in which the master device establishes the soft error detection windows **902** and **904**. However, an absence of soft decisions residing within the sliding idle mode detection windows **952** and **954** causes the slave device to determine that the master device is not transmitting data. When this decision is made, the slave device determines that it is receiving known data from the master device during time period **962** (Step **758** of FIG. 7B) and retrains its DFE using the known data (Step **760** of FIG. 7B).

FIG. 8B is a flow chart illustrating differing EMI detection operations according to an embodiment in accordance with the present disclosure. With the operations of FIG. 8B, one or more of a Signal to Interference Ratio (SNR) threshold level, a Bit Error Rate (BER) threshold level, or a Block Error Rate (BLER) threshold level are established (Step **852**). The SNR, BER, and/or BLER of the wired link is then determined (Step **854**). If the SNR/BER/BLER threshold is met at Step **856**, operation proceeds to Step **858** where link recovery operations are initiated. If the SNR/BER/BLER threshold is not met at Step **856**, operation returns to Step **854** where the quality of the wired link is again determined.

FIG. **10** is a flow chart illustrating data buffering and retransmission operations in accordance with the present disclosure. There are multiple ways to deal with lost packets. Application or Network layers may simply drop the lost data packets or, alternately, request a repeated transmission of lost packets. Forward Error Correction (FEC) with large enough interleaving or PHY layer Automatic Retransmission reQuest (ARQ) operations may be used to correct for the errors.

Another option is that the data packets are buffered and retransmitted by the PHY when EMI is detected. This could be a good choice if offered traffic is less than PHY full data rate. Since the interruption is short in duration, a small increase in PHY data rate may cover for the lost bandwidth. Alternatively, implementing a flow control in PHY (IEEE Pause frame) could provide a loss less data transmission at near full throughput without increasing the PHY data rate. With the operations of FIG. **10**, the device receives new data for transmission from its processing circuitry or from another device (Step **1002**). The device then buffers the new data in its memory/buffer (Step **1004**). The device then determines whether EMI recovery operations have been initiated (decision step **1006**). When the device is operating normally, it transmits new data from its data buffer onto the wired link (Step **1008**). However, when the device determines that it is in an EMI recovery mode, it determines what data has been transmitted onto the wired link that is likely corrupted by the EMI (Step **1010**). Then, when the EMI recovery operations are completed, it retransmits the data that it has determined was likely corrupted by the EMI (Step **1012**). From Step **1012**, operations return to Step **1008**.

The present disclosure has been described, at least in part, in terms of one or more embodiments. An embodiment of the present disclosure is used herein to illustrate the present disclosure, an aspect thereof, a feature thereof, a concept thereof, and/or an example thereof. A physical embodiment of an apparatus, an article of manufacture, a machine, and/or of a process that embodies the present disclosure may include one or more of the aspects, features, concepts, examples, etc. described with reference to one or more of the embodiments discussed herein. Further, from figure to figure, the embodiments may incorporate the same or similarly named functions, steps, modules, etc. that may use the same or different reference numbers and, as such, the functions, steps, modules, etc. may be the same or similar functions, steps, modules, etc. or different ones.

The present disclosure has been described above with the aid of functional building blocks illustrating the performance of certain significant functions. The boundaries of these functional building blocks have been arbitrarily defined for convenience of description. Alternate boundaries could be defined as long as the certain significant functions are appropriately performed. Similarly, flow diagram blocks may also have been arbitrarily defined herein to illustrate certain significant functionality. To the extent used, the flow diagram block boundaries and sequence could have been defined otherwise and still perform the certain significant functionality. Such alternate definitions of both functional building blocks and flow diagram blocks and sequences are thus within the scope and spirit of the claimed disclosure. One of average skill in the art will also recognize that the functional building blocks, and other illustrative blocks, modules and components herein, can be implemented as illustrated or by discrete components, application specific integrated circuits, processors executing appropriate software and the like or any combination thereof.

What is claimed is:

1. A vehicle communication network device comprising:

a transceiver configured to communicatively couple with a remote transceiver of another vehicle communication network device via a wired media; and

processing circuitry coupled to the transceiver, wherein the processing circuitry and transceiver are configured to:

detect interference on the wired media that exceeds an interference threshold level by determining that a number of soft decisions that fall in a sliding soft decision error window exceeds an error threshold;

upon the detection, enter a quiet mode during which no data is transmitted on the wired media;

after exiting the quiet mode, enter an idle mode during which known data is transmitted on the wired media;

receive known data from the remote transceiver;

retrain the transceiver based upon the known data; and

after retraining the transceiver, exchange data with the remote transceiver.

2. The vehicle communication network device of claim **1**, wherein the processing circuitry and transceiver are further configured to:

buffer data for transmission;

upon the detection, determine buffered data that was likely corrupted by the interference; and

after retraining, retransmit the determined buffered data.

3. The vehicle communication network device of claim **1**, wherein the wired media comprises an unshielded twisted pair wire.

4. The vehicle communication network device of claim **3**, wherein the transceiver further provides power to the remote transceiver via the unshielded twisted pair wire.

5. The vehicle communication network device of claim **1**, wherein the transceiver supports wired local area network communications.

6. The vehicle communication network device of claim **1**, wherein in detecting that the interference on the wired media exceeds the interference threshold level, the processing circuitry and transceiver are further configured to detect that a signal quality available on the wired media is less than at least one of a Signal to Interference Ratio (SNR) threshold level, a Bit Error Rate (BER) threshold level, or a Block Error Rate (BLER) threshold level.

7. The vehicle communication network device of claim **1**:

further comprising a Decision Feedback Equalizer (DFE) configured to equalize incoming data; and

wherein retraining the transceiver using the known data comprises retraining the DFE using the known data.

8. A method of operating a vehicle communication network device comprising:

communicating with a remote transceiver of another vehicle communication network device via a transceiver and wired media;

detecting interference on the wired media that exceeds an interference threshold level by determining that a number of soft decisions that fall into a sliding soft decision error window exceeds an error threshold;

upon the detection, entering a quiet mode during which no data is transmitted on the wired media;

after exiting the quiet mode, entering an idle mode during which known data is transmitted on the wired media;

receiving known data from the remote transceiver;

retraining the transceiver based upon the known data; and

after retraining the transceiver, exchanging data with the remote transceiver.

9. The method of claim **8**, further comprising:

buffering data for transmission;

upon the detection, determining buffered data that was likely corrupted by the interference; and

after retraining, retransmitting the determined buffered data.

10. The method of claim **8**, wherein the wired media comprises an unshielded twisted pair wire.

11. The method of claim **10**, further comprising providing power to the remote transceiver via the unshielded twisted pair wire.

12. The method of claim 8, further comprising the transceiver supporting wired local area network communications.

13. The method of claim 8, wherein in detecting that the interference on the wired media exceeds the interference threshold level, the method further comprises detecting that a signal quality available on the wired media falls is less than at least one of a Signal to Interference Ratio (SNR) threshold level, a Bit Error Rate (BER) threshold level, or a Block Error Rate (BLER) threshold level.

14. The method of claim 8:

further comprising equalizing incoming data using a Decision Feedback Equalizer (DFE); and

wherein retraining the transceiver using the known data comprises retraining the DFE using the known data.

15. A method of operating a vehicle communication network device comprising:

buffering data for transmission to a remote transceiver of another vehicle communication network device via a transceiver and wired media;

detecting interference on the wired media that exceeds an interference threshold level by determining that a number of soft decisions that fall into a sliding soft decision error window exceeds an error threshold;

upon the detection, entering a quiet mode during which no data is transmitted on the wired media and determining buffered data that was likely corrupted by the interference;

after exiting the quiet mode, entering an idle mode during which known data is transmitted on the wired media;

receiving known data from the remote transceiver;

retraining the transceiver based upon the known data; and

after retraining the transceiver, exchanging data with the remote transceiver including retransmitting the determined buffered data.

16. The method of claim 15, wherein the wired media comprises an unshielded twisted pair wire.

17. The method of claim 16, further comprising providing power to the remote transceiver via the unshielded twisted pair wire.

18. The method of claim 15, further comprising the transceiver supporting wired local area network communications.

19. The method of claim 15, wherein in detecting that the interference on the wired media exceeds the interference threshold level, the method further comprises detecting that a signal quality available on the wired media falls is less than at least one of a Signal to Interference Ratio (SNR) threshold level, a Bit Error Rate (BER) threshold level, or a Block Error Rate (BLER) threshold level.

20. The method of claim 15:

further comprising equalizing incoming data using a Decision Feedback Equalizer (DFE); and

wherein retraining the transceiver using the known data comprises retraining the DFE using the known data.

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